FIG. 1

$$Pb_{\alpha}[(Mn_{1/3}Nb_{2/3})_x Ti_y Zr_z]O_3 \quad \cdots \text{ formula (1)}$$

In formula (1),

$0.95 \leq \alpha \leq 1.02$,

$0.02 \leq x \leq 0.15$,

$0.48 \leq y \leq 0.62$,

$0.30 \leq z \leq 0.50$; and

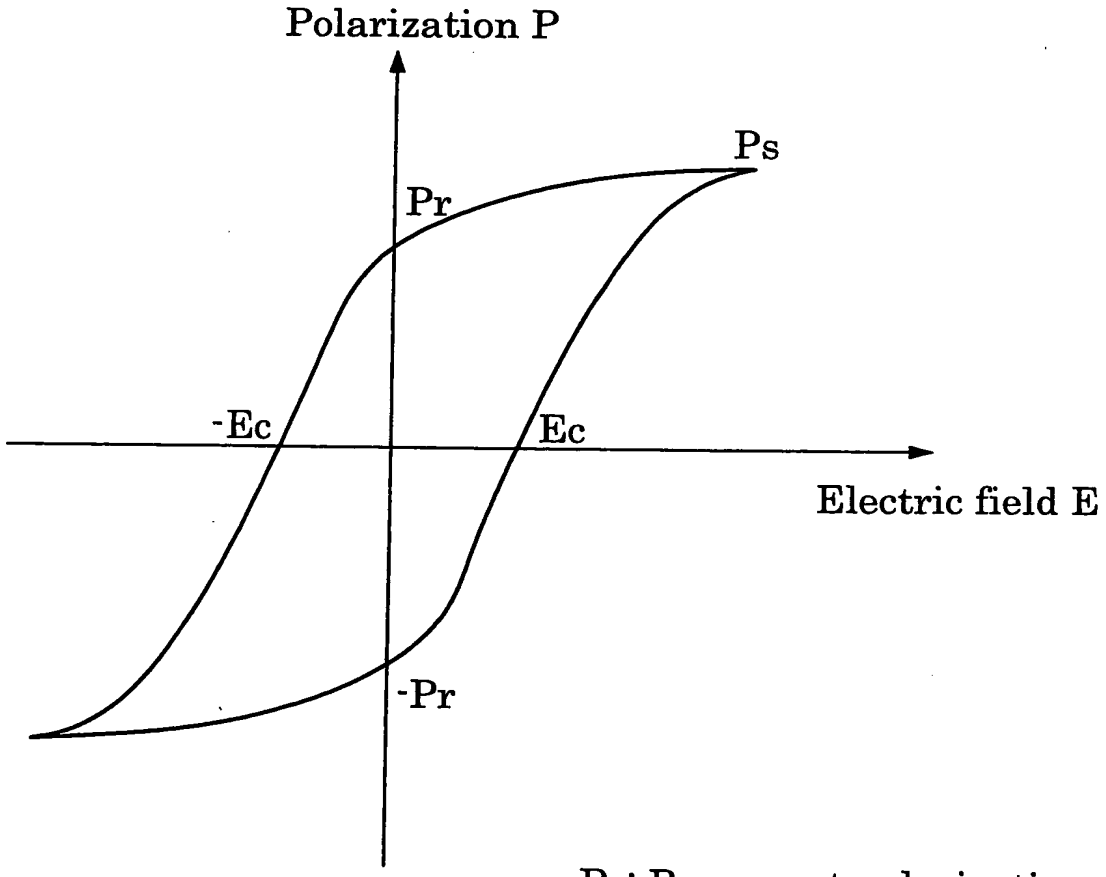
α, x, y and z are respectively given in molar ratio.

$$k_{15} = \sqrt{\frac{\pi}{2} \cdot \frac{Fr}{Fa} \cot\left(\frac{\pi}{2} \cdot \frac{Fr}{Fa}\right)} \quad \cdots \text{ formula (2)}$$

In formula (2), Fr represents a resonant frequency and Fa represents an anti-resonant frequency.

FIG. 2

Hysteresis loop for polarization P and electric field E



Pr: Remanent polarization
Ps: Saturation polarization
Ec: Coercive electric field

FIG. 3A

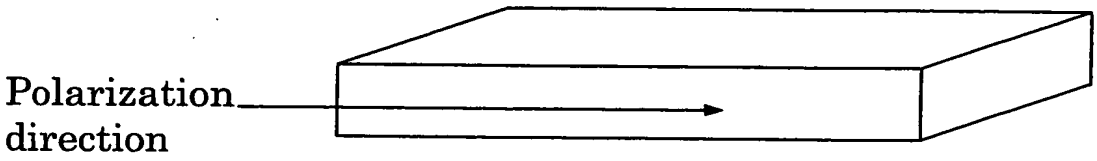


FIG. 3B

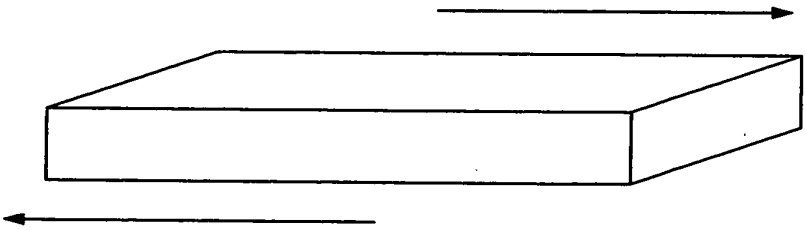


FIG. 4

$$F0 = Fr\sqrt{1+\frac{C_1}{C_0+C_L}} \quad \cdots \text{ formula (3)}$$

In formula (3), F0 represents an oscillation frequency, Fr represents a resonant frequency, C_1 represents a motional capacitance and C_0 represents a shunt capacitance; and C_L is defined by formula (6).

$$C_1 = \frac{Fa^2 - Fr^2}{Fa^2} Cd \quad \cdots \text{ formula (4)}$$

In formula (4), C_1 represents a motional capacitance, Fa represents an anti-resonant frequency, Fr represents a resonant frequency, and Cd represents a free capacitance.

FIG. 5

$$C_0 = Cd - C_1 \quad \cdots \text{ formula (5)}$$

In formula (5), C_0 represents a shunt capacitance, Cd represents a free capacitance, and C_1 represents a motional capacitance.

$$C_L = \frac{C_{L1} \cdot C_{L2}}{C_{L1} + C_{L2}} \quad \cdots \text{ formula (6)}$$

$$\Rightarrow \frac{C_{L1}}{2} \quad (C_{L1} = C_{L2})$$

In formula (6), C_{L1} represents a load capacitance and C_{L2} represents another load capacitance.

FIG. 6

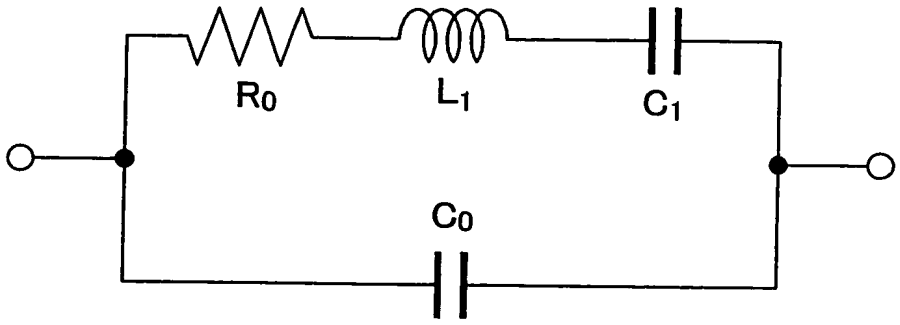


FIG. 7

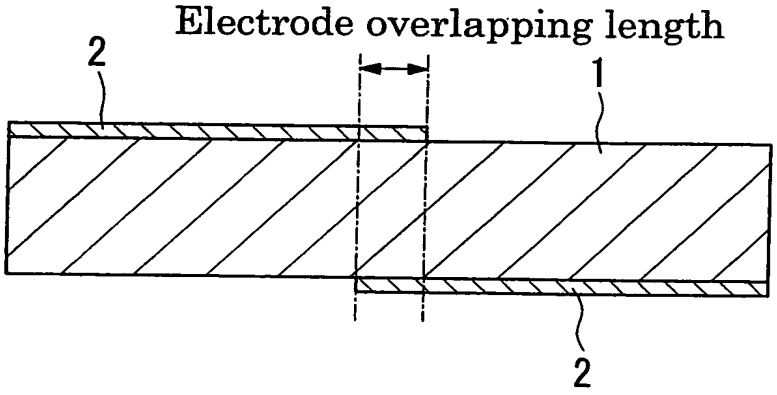


FIG. 8

Sample No.	Additive(s)	Load (wt%)	Δk15 (%)	Q_{max}	Polarization conditions		
					Tempe-rature (°C)	Time (min)	Electric field (kV/mm)
* 1	None	—	−4.4	120	150	1	3
2	Cr_2O_3	0.05	−1.9	97			
3		0.10	−1.2	130			
4		0.20	−2.0	129			
* 5		0.30	−3.7	108			
* 6		0.50	−4.8	81			
* 7	$MnCO_3$	0.05	−4.5	81			
* 8		0.20	−4.5	129			
* 9		0.30	−4.7	120			
* 10		0.50	−4.2	85			
11	Cr_2O_3 $MnCO_3$	0.05 0.05	−2.1	118			

FIG. 9

Sample No.	Additive(s)	Load (wt%)	Δk15 (%)	ΔF0 (%)	ΔFr (%)
12	Cr_2O_3	0.05	−0.58	−0.02	0.03
13		0.10	−0.49	−0.03	0.04
14		0.20	−0.60	−0.03	0.01

FIG. 10

Sample No.	$Pb_\alpha[(Mn_{1/3}Nb_{2/3})_xTi_yZr_z]O_3$				Cr_2O_3 [wt%]	Δk15 (%)	Q_{max}
	α	x	y	z			
15	0.98	0.05	0.55	0.40	0.05	−1.9	92
16		0.13	0.49	0.38		−2.9	177
17		0.09	0.60	0.31		−1.8	98
18		0.03	0.48	0.49		−2.8	110
19	0.995	0.05	0.55	0.40	0.10	−1.9	85
20		0.03	0.48	0.49		−1.1	76